Dusty disk-planet simulations

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Credit: NASA/JPL/CalTech

Compact 7-planet system

How to form:

disk migration? (Tamayo et al., 2017)

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Dusty gas dynamics

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Compact 7-planet system

How to form: disk migration? (Tamayo et al., 2017)
Disk-planet interaction

Surface density perturbation

- Inner wake → migrate out
- Outer wake → migrate in
- Co-rotation torques: sensitive to thermal structure

Pluto simulations
Disk-planet interaction

Pluto simulation vs. semi-analytic models

- Models from Paardekooper et al. (2010)
- Co-rotation torque saturates without dissipative processes
Making planets require dust

(Testi et al., 2014)

- Planetesimal formation requires high dust/gas ratios
- Dust-rich disk-planet interactions?
- Modeling dust-gas interaction properly is challenging
A simplified framework for dusty-gas dynamics

Model for a mixture of polytropic gas ($P \propto \rho_{\text{gas}}^\Gamma$) and small dust grains

\[
\begin{align*}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0, \\
\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} &= -\frac{1}{\rho} \nabla P - \nabla \Phi, \\
\frac{\partial P}{\partial t} + \mathbf{v} \cdot \nabla P &= -\Gamma P \nabla \cdot \mathbf{v} + \frac{\Gamma P}{\rho_{\text{gas}}} \nabla \cdot (f_{\text{dust}} t_{\text{stop}} \nabla P) .
\end{align*}
\]

(Lin & Youdin, in prep.)

- Dust-gas friction
  - $f_{\text{dust}} =$ dust fraction
  - $t_{\text{stop}} =$ decay timescale of $|\mathbf{v}_{\text{dust}} - \mathbf{v}_{\text{gas}}|$ due to friction

- Implemented by tweaking the PLUTO code — dPLUTO \(^1\)

\(^1\)https://github.com/minkailin/dPLUTO
Dusty-gas effect I: pseudo-cooling

- Solids have no thermal pressure
- Solid-gas coupling $\rightarrow$ lowers effective temperature of the dust-gas mixture

\[
\text{Pressure} = \frac{\mathcal{R}}{\mu} T \rho_{\text{gas}}
\]

\[
= \frac{\mathcal{R}}{\mu} \frac{T \rho_{\text{gas}}}{\rho_{\text{total}}} \rho_{\text{total}}
\]

\[
\rho_{\text{total}} = \rho_{\text{gas}} + \rho_{\text{dust}}
\]

So $T_{\text{effective}} < T$

Built into simplified dust-gas framework
Dusty-gas effect II: particle drift

- Drag forces cause dust to accumulate at pressure bumps
- Built into simplified dust-gas framework
Dusty disk-planet simulations with dPluto

\[ t_{\text{stop}} \Omega_K = 10^{-3} \]

\[ \Sigma_{\text{dust}} = 0.01 \Sigma_{\text{gas}} \]

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- Torque units account for pseudo-cooling due to dust
Dusty disk-planet simulations with dPLUTO

\[ \Sigma_{\text{dust}} = 0.01\Sigma_{\text{gas}} \]

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- Resolution: 40 cells per local length-scale in \( r \); 20 in \( \phi \)
Dusty disk-planet simulations with dPLUTO

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Summer tasks

- Numerical resolution tests
- Customized experiments to filter out pre-known effects of dust-loading
- Analyze simulation data to understand origin of overstable torques
- When does it happen?
References